CHAPTER 243

The Variation of Floc sizes within a turbidity maximum at spring and neap tides

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Abstract

The variation of floc size has been measured during spring and neap tides at a height of 0.5 m above the bed in the turbidity maximum of the Tamar Estuary, UK. Two size populations were present. Small flocs were eroded from the bed during spring flood tides and were transported up estuary. Large flocs were dominant at other times, particularly just after high water when differential settling concentrated large flocs near the tip of the salt intrusion.

Introduction

Many studies have shown that the size of flocs of cohesive sediment are functions of salinity, temperature, concentration (Owen, 1970), turbulent shearing (Burban et al, 1989) and other factors, such as surface ionic charge (Hunter & Liss, 1982). Most of these studies have been carried out in the laboratory, and the results interpreted in terms of known field situations. However, many of the flocs are fragile and floc sizes and size distributions obtained from samples are not good representations of those present in-situ (Gibbs & Konwar, 1983). There have been few studies where the undisturbed floc sizes have been measured in-situ. Gibbs et al (1989), Eisma et al (1990), Wells (1989), have used an underwater camera; Bale and Morris (1987) a marinized Malvern laser particle sizer, and van Leussen & Cornelisse (1992) an underwater video system.

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Despite use of these techniques, it is still not clear what is the spatial and temporal distribution of floc sizes within a turbidity maximum, and what are the controlling processes.

This paper describes an in-situ study of the floc size distribution in the turbidity maximum of a partially mixed estuary carried out over spring and neap tides. The objectives were to consider the question of whether turbulence affects floc sizes in estuaries, but initially a description of the tidal variation of floc size was necessary.

Methods

A Malvern laser sizer was mounted on a bed frame at a height of 50 cm above the bed. This instrument, described by Bale & Morris (1987), measures the diffraction of a laser beam by suspended particles in a sampling volume of approximately 1 cm^3. The sizer produces a percentage size distribution in sixteen bands for diameters from 564 μm to less than 5.8 μm. Two distribution samples were recorded every 20 minutes.

Also mounted at a height of 50 cm were two Valeport annular electromagnetic flowmeters. These were mounted orthogonally at 45° to the flow direction so that the longitudinal and lateral components of the flow could be resolved, together with two estimates of the vertical component. Downing Optical Backscatter Gauges (OBS) were mounted at 23 and 50 cm height.

Through depth profiles were carried out every 20 mins to obtain profiles of salinity, temperature, velocity and suspended solids. This paper will concentrate on the results from the vertical profiles and the floc sizer.

Measurements were carried out over two spring tides (4, 5 July 1989) when the tidal range was 4.3 to 4.2 m, and two neap tidal cycles (28, 29 June 1989) with tidal range of 2.9 to 3.0 m at a position near Calstock on the Tamar Estuary (Fig 1). This position, 8 km from the head of the estuary, was within the tidal trajectory of the turbidity maximum and in the area where significant variations of concentration were likely during the tide, together with erosion and settling.

Results

General Structure

During the neap tide (Fig 2) the rig was located within the river water at low water, with the turbidity maximum to seaward. As the tide flooded, the turbidity maximum was pushed landwards, with concentrations of 500 mgl^{-1} being measured near the bed. Maximum velocities at this point coincided with the peak of the concentrations in the turbidity maximum. Once the peak of the turbidity maximum had passed, the saline intrusion appeared as a well mixed water column, rather like a piston pushing up the estuary. At HW there was a period of almost 2 hours of low velocities and salinities of >12^{o}/oo near the bed. The surface outflow started before high water and the almost stationary salt intrusion was gradually eroded down to the bed over a period of about 2 hours with intense shearing at a rate of about $0.2s^{-1}$ at the interface. Once the salt intrusion had been eroded, and the ebb current penetrated to the bed, the turbidity maximum was carried back on the ebb tide, but with peak concentrations about half and peak velocities about two-thirds those on the flood.

The pattern of change over a spring tidal cycle was remarkably similar, but with somewhat enhanced velocities and concentrations (Figure 3). On the flood tide concentrations in the turbidity maximum reached 1000 mgl^{-1} with velocities of 1 ms^{-1}. On the ebb tide concentrations were again about half that on the flood, but with velocities the same as that on neaps. The other two tidal cycles gave almost identical information for spring and neap tides.

Floc Sizes

The size distributions show that there were two predominent modes in the floc distribution, flocs of less than 5.8 µm and flocs of 100 µm and larger. The relative proportions of these varied consistently through the tide. The smallest particles are thought to be individual grains and microflocs with small settling velocities and with stable structure. The largest flocs are likely to have been prone to break-up during shearing, and to rapid settling at times of low currents. Consequently their reltive numbers were related to current speed.

During the first part of the flood tide in the water upstream of the turbidity maximum, the flocs were predominently in the fine sizes. Within the turbidity maximum on the flood tide, there was a significant difference between spring and neap tides (Fig 4). On neap tides there was a broad peak of large flocs centred at about 200 µm, and with very few small flocs. During spring tides, however, there was a predominence of fine flocs, with no large flocs. There were more flocs in the size range 10-100 μm at spring tides, and these may be the result of turbulent breakup of the larger flocs present at neap tides.

At the seaward end of the turbidity maximum, encountered a little later in the flood tide the proportion of fine flocs diminished rapidly, and large flocs predominated. This period extended over high water and into the beginning of the ebb tide. The peak of the distribution became more and more sharp (better sorted), until during the time when the salt intrusion was being eroded, there were relatively few flocs of less than 100 μm (Figure 5). There is a remarkable similarity between the size distributions at this phase of the tide between neap and spring tides. It is also likely at this time that there were larger flocs still within the water that were beyond the resolution of the instrument.

Within the turbidity maximum on the ebb the proportion of large flocs diminished and the proportion of flocs in the size range 30-200 μm increased (Figure 6). The differences between spring and neap tides in the fraction greater than 10 μm in the ebb turbidity maximum is small in comparison with those in the turbidity maximum on the flood tide. This may reflect the similarity in current velocities and in concentrations on neap and spring ebb tides, and the contrast on the respective flood tides.

Consequently there appears to be a significant variation in floc sizes through the turbidity maximum, with large flocs predominating at the downstream end of the maximum. The fine sizes are present at spring tides and particularly during the maximum flood current.

Discussion

The most striking feature is that the spring flood turbidity maximum consisted almost entirely of particles less than 6 μm in diameter. The neap flood turbidity maximum consisted mostly of larger particles. The active event seemed to be the spring flood tide when new primary particles were eroded off the bed. These were carried upstream past the rig, but did not all return on the ebb. The distribution of larger particles remained remarkably similar on each ebb and was also similar to that of the neap flood. These observations suggest that there are two populations of particles present, with different characteristics.

It is surprising that the two populations of flocs can be so distinctive especially in the energetic spring tide situation. The dramatic change in the floc size distribution was associated with the erosion and retreat of the salt intrusion prior to the passage of the main part of the turbidity maximum on the ebb tide. As the salt intrustion was entrained into the upper layer and the interface was eroded down to the height of the instrument, the particle size became steadily larger and better sorted. When the interface was below the level of the sensors, and they were in the upper seaward flowing brackish layer, the sizes abruptly decreased. The size variation during this period may be explained by comparing the rate of entrainment with the particle settling velocity. The entrainment rate of ~1.5m hr^{-1} or the rate of descent of the interface, is comparable with the settling velocity, measured in-situ, of about 200 µm (Fennessy, pers comm). Thus flocs of this size would tend through settling to accumulate at the interface. Larger particles would settle through into the lower layer and reach the bed, though the larger flocs may have an effective density low enough to become neutrally buoyant at the interface. Fine particles would be sheared off downstream in the brackish water layer. Thus, as the thickness of the lower layer reduced, the larger particles became concentrated at the tip of the salt intrusion. This process will enhance the effects of differential settling which will cause larger particles to accumulate near the bed. Differential settling will also take place throughout the turbidity maxima, but redispersion will occur during the maximum currents. In this case some breakup of the flocs is likely to broaden the peak of large flocs and reduce the modal diameter. Thus largest flocs are retained at the downstream end of the turbidity maximum. Gibbs et al (1989) have found in the Gironde Estuary that the maximum of floc size is 30 km seaward of the turbidity maximum, and there are indications of similar floc size distributions within the turbidity maximum of other estuaries (Eisma et al, 1991).

On the flood the maximum is advected upriver picking up any large flocs that settled out during the ebb. On spring tides primary particles are also eroded from the bed to form the bulk of the flocs. The turbidity maximum passes upstream and, since less particulate matter is carried downstream on the ebb, deposition occurs. Differential settling takes place and those settling into the salt intrusion are separated by the velocity shear from the finer flocs. The larger flocs are then re-eroded on the following flood tide.

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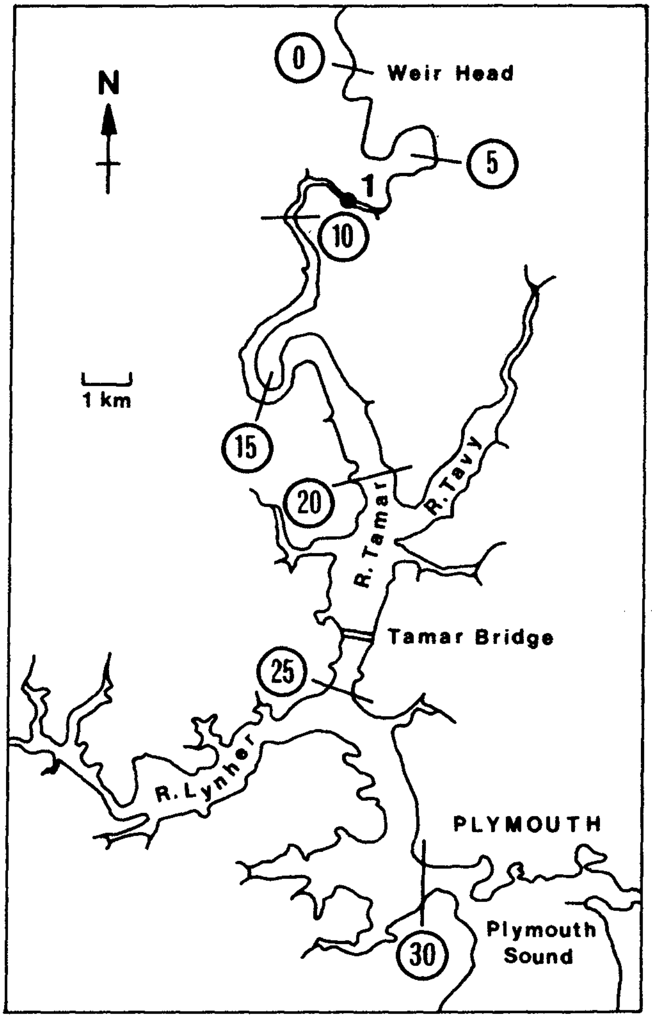

Figure 1. Tamar estuary, Devon, S. England showing location of measurements (Station 1) and distances in Km from the tidal limit.

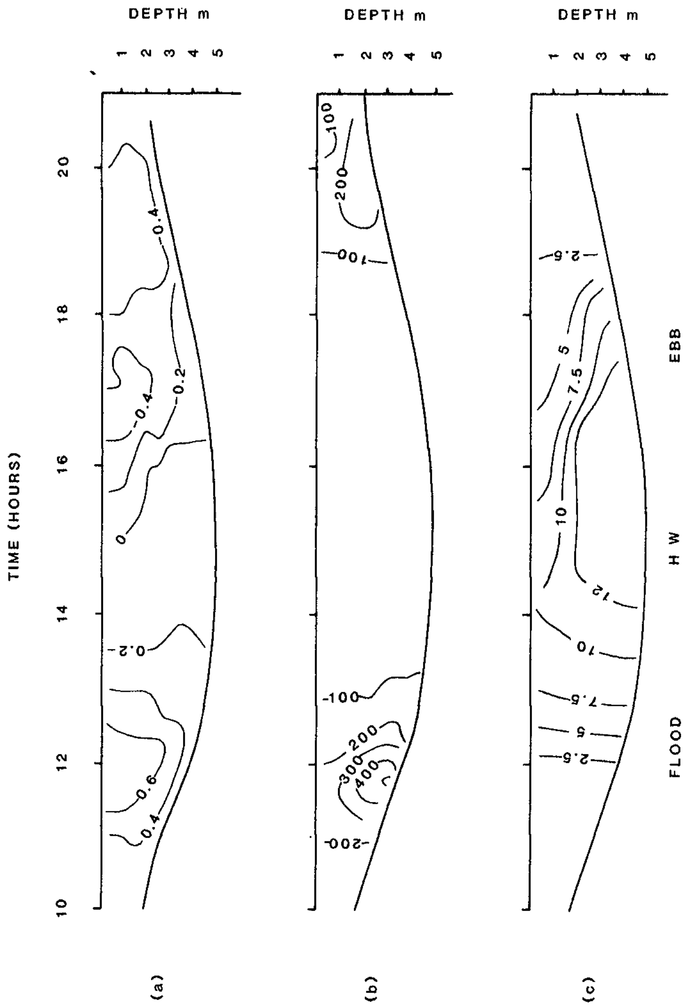

Figure 2. Neap tide variation in: a) current velocity ms^{-1}, b) concentration mgl^{-1}, c) salinity ppt.

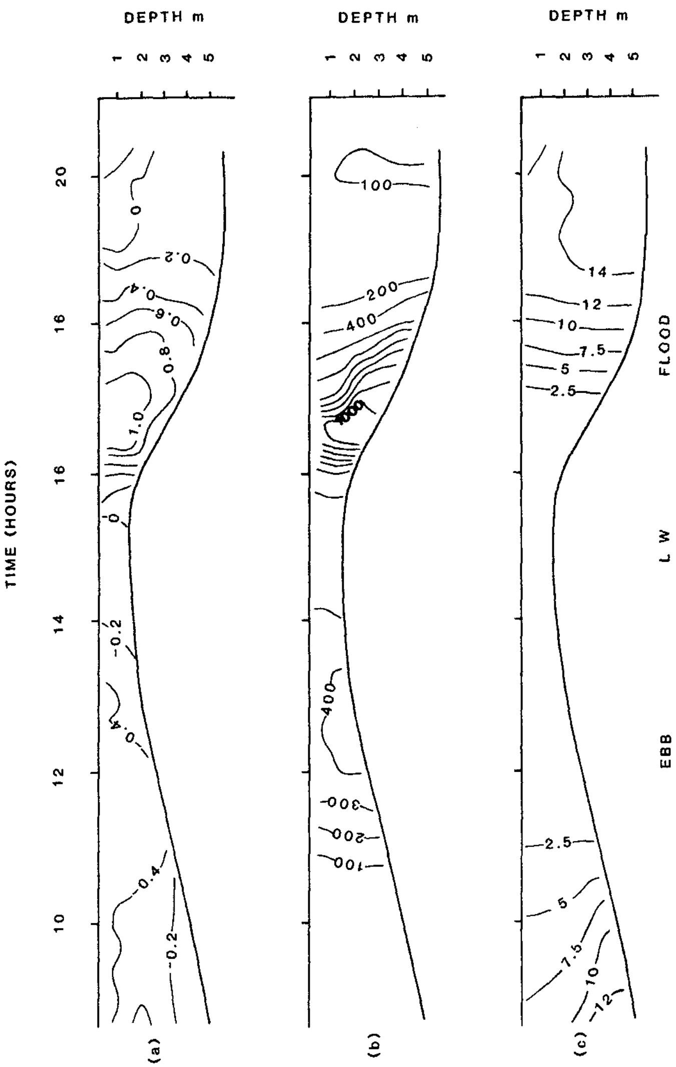

Figure 3. Spring tide variation in: current velocity ms^{-1}, b) concentration mgl^{-1}, c) salinity ppt.

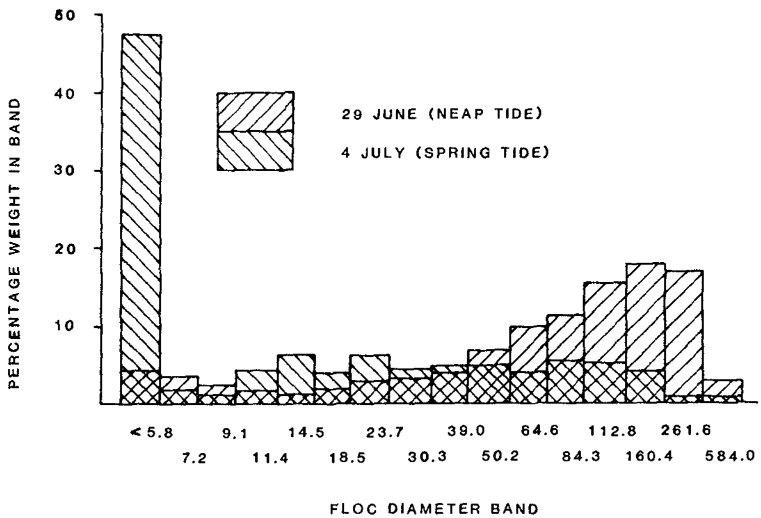

Figure 4. Floc size distribution during the flood turbidity maximum at neap and spring tides.

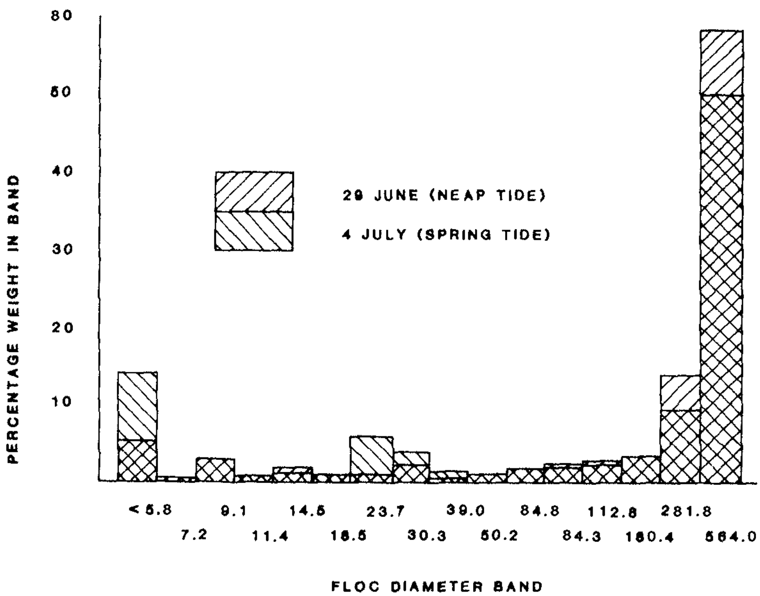

Figure 5. Floc size distribution during the period of salt intrusion erosion at neap and spring tides.

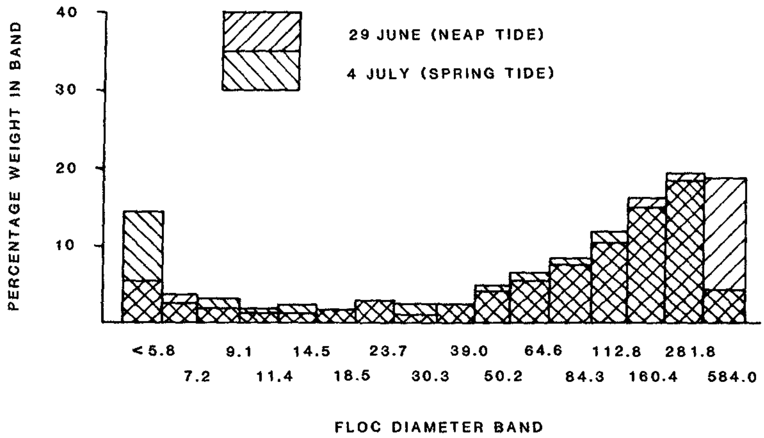

Figure 6. Floc size distribution during the ebb turbidity maximum at neap and spring tides.